Technical Description for the K-12 Model

12/11/2001

Data Source

Energy consumption and building characteristics data for the analysis of K-12 schools were obtained from the 1995 CBECS (Commercial Buildings Expenditures and Consumption Survey 1995, EIA).

Data Set and Basic Filters

To yield as nearly a homogenous data set of K-12 schools – single building and multi-building facilities as well as public and private schools – two screens were applied to the CBECS data set. These screens were intended to be as inclusive as possible with regard to individual records where confidence was high that the records did indeed represent a K-12 school. In both screens, additional basic filters were applied for the purpose of obtaining a more homogenous dataset. The basic filters that were applied are presented below. Those data records that did not meet any of these criteria were removed from the analysis.

Basic Filters

Description	CBECS Variable	Criteria
Gross Building or Facility Area (ft^2)	SQFT	> 4,999
Weekly Hours of Use	WKHRS	> 29
# of Months in Use out of past 12	MONUSE	> 7
Annual Electricity Consumption (Btu)	ELBTU	> 0
Annual Electricity Consumption (Btu)	ELBTU	< 10,000,000,000,000
Classroom Seating Capacity	EDSEAT	< 99996
Occupant Density (#/1,000 ft^2)	NWKER/(SQFT/1000)	> 0.3 and < 10

Once done, screens were applied to capture different segments of the population of K-12 schools in CBECS. The intent of the first screen listed below was to capture the traditional, local government owned schools including both single building K-12 schools and multi-building K-12 school facilities.

Local Government-Owned K-12 School Screen

Filter Description	CBECS Variable	Criteria	Criteria Description
Principal Building Activity	PBA	= 14	Education
Type of Gov't Agency Owned By	GOVTYP	= 3	Local Government Owned
Primary Facility Activity	FACACT	= 1	Primary or Secondary School
Primary Facility Activity	FACACT	= 99	Not Ascertained

The inclusion of records where the CBECS variable FACACT = 99 (Not Ascertained) represents single buildings. Likewise, records where FACACT ≠ 99 indicate a multi-building facility. Both conditions can be confirmed by including the FACIL variable in CBECS which asks (yes/no) if the building is part of a multi-building facility or complex. No additional granularity exists to indicate definitively that the records are either primary or secondary schools in these instances. However, it was presumed that the overwhelming majority of the records where FACACT = 99 whose principal building activity was "Education" (PBA = 14), and who were owned by a local government agency (GOVTYP = 3) would be single building, K-12 schools.

The Local Government-Owned K-12 School screen as detailed above resulted in 265 records. Of these, 133 were specifically noted as a primary or secondary school facilities (FACACT = 1) and 132 were single building, education buildings (FACACT = 99) assumed to be primarily K-12 schools.

The intent of the second screen was to add the non-local government-owned (private, Federal, and State) K-12 schools to the dataset. The assumption in the first screen was that

stand-alone education buildings owned by local governments would be primarily K-12 schools, however because there was less confidence in this assumption as it applied to non-local government owned buildings only multi-building facilities were included in the second screen as shown below.

Non-Local Government-Owned K-12 School Screen

Filter Description	CBECS Variable	Criteria	Criteria Description
Principal Building Activity	PBA	= 14	Education
Type of Gov't Agency Owned By	GOVTYP	≠ 3	Not Local Government Owned
Primary Facility Activity	FACACT	= 1	Primary or Secondary School

The Non-Local Government-Owned K-12 School screen as detailed above resulted in 60 records yielding a grand total of 325 records for the analysis. Of these, 193 were specifically noted as a primary or secondary school facilities (FACACT = 1) and 132 were single building, education buildings (FACACT = 99) assumed to be primarily K-12 schools. More basic statistics for this data set is available in Appendix A.

Dependent Variable

The basis of the regression, that is, the dependent variable chosen for the regression was annual source energy use intensity (Source EUI) measured in kBtu/ft^2-year. Source EUI was chosen over simply source energy since it was determined that the explanatory power of the building size term was significantly higher than any other term. Also, energy intensity be it site or source, is a commonly used and understood way to characterize and compare building energy performance amongst groups of buildings.

Independent Variables

The following independent variables were examined for their significance and correlation with the dependent variable as well as with the other independent variables.

HDD65	heating degree days
CDD65	cooling degree days
DD	total heating and cooling degree days
COOLP	percentage of the gross floor area that is mechanically cooled
HEATP	percentage of the gross floor area that heated
PCTRM	number of personal computers (PCs)
PCDens	number of PCs per 1,000 ft^2
SQFT	gross building square footage
EDSEAT	number of students that can be seated in all of the classrooms in the building at one time
COOL	presence (Y/N) of mechanical cooling equipment in the facility
COOK	presence (Y/N) of an area dedicated to cooking and serving food
WKHRS	average weekly hours when building is at least 50% occupied
MONUSE	number of months the building was in use during previous 12 months
NWKER	number of workers during the main occupancy of the building
OccDens	number of workers per 1,000 ft^2 during the main occupancy of the building

Weighting Factors

The stated purpose of CBECS is to develop and publish estimates of population values. Thus, the CBECS sample is designed so that survey responses can be used to estimate characteristics of the entire stock of commercial buildings in the United States (EIA, CBECS 1995). CBECS calculates basic sampling weights that relate sampled buildings to the entire stock of commercial buildings. While sampling weights – or weighting factors – are necessary to estimate characteristics of the entire stock of U.S. commercial buildings, they are not necessary to perform meaningful regression analyses. Thus, the CBECS weighting factors were not used in the analysis of the K-12 regression modeling.

Source Energy

The analysis relied upon source energy consumption versus the site energy consumption provided in CBECS 1995. A one-page discussion regarding the use of the source energy convention versus the site energy convention can be viewed and downloaded via www.energystar.gov. The following conversion factors were used to obtain source energy consumption from the site energy consumption:

Fuel Type	Site (kBtu)	Source (kBtu)
Electricity	1	3.013
Natural Gas	1	1.024
Fuel Oil	1	1
Steam	1	1.38
Hot Water	1	1

Regression Results

The objective of the analysis was to determine the significant drivers or building characteristics of Source EUI. Prior to undertaking this analysis it was first necessary to understand the explanatory power of the annual source energy consumption to gross building area relationship.

A simple regression model was examined with annual source energy consumption assigned as the dependent variable and gross building area as the independent variable. The analysis revealed a R-squared for this simple model to be 0.78. Moving the square foot term to the dependent variable side – Source EUI – effectively means that a regression model using Source EUI as the dependent variable is attempting to explain the remaining 22% ([1-0.78]*100) since the square foot term is already explaining 78% of the variability in source energy use.

Table-1 presents the results of the regression analysis. The independent variables used were COOKING, COOLP, HDD, LNSQFT, SEATDENS, WKHRS, and MONUSE. While not showing to be significant by the standard statistical definition where the T-stat is greater than +/- 2.0, weekly hours (WKHRS) and months in use (MONUSE) were left in the model since beta test results of an earlier model indicated a strong preference by users to keep the variables in. Principally, the rationale centered around the fact that a significant number of schools – especially those in more rural areas – were used by the local community after school hours and often during the summer break. The LNSQFT variable was kept in the model because it was believed – based on previous analyses with other building types – that Source EUI varied with the natural log of building size. The addition of these three variables did not adversely affect the model.

The R-squared of the Source EUI model was found to be 0.20, thus the overall effective R-squared of the entire model is:

$$R\text{-squared}_{Effective} = 0.78 + ((1-0.78) \times 0.20)$$

$$R\text{-squared}_{Effective} = 0.82$$

Table-2 presents the basic statistics – mean/median, minimum/maximum, and standard deviation – for each of the model variables.

Table-1 Regression Model Results

Dependent Variable: SOURCE_EUI
Method: Least Squares
Date: 03/27/00 Time: 12:05
Sample(adjusted): 1 325
Included observations: 325 after adjusting endpoints
White Heteroskedasticity-Consistent Standard Errors & Covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	67.93262	92.90065	0.731239	0.4652
COOKING	18.36200	10.27226	1.787533	0.0748
COOLP	0.241595	0.131759	1.833617	0.0676
HDD	0.008969	0.002558	3.506556	0.0005
LN_SQFT	-8.386401	6.959261	-1.205071	0.2291
SEATDENS	3.798571	0.941517	4.034524	0.0001
WKHRS	0.319756	0.213242	1.499502	0.1347
MONUSE	1.856469	4.132937	0.449189	0.6536

R-squared	0.197923	Mean dependent var	132.2889
Adjusted R-squared	0.180212	S.D. dependent var	88.18511
S.E. of regression	79.84471	Akaike info criterion	11.62235

Table-2 Basic Statistics, Model Variables

	Cooking	Cooling%	HDD	Ln(SqFt)	SeatDens	WkHrs	MonUse	SqFt	SourceEUI
Mean	0.708	50.8	4602	10.77	13.00	56.1	11.2	75,844	132.3
Median	1.000	50.0	5069	10.82	10.67	50.0	12.0	50,000	115.6
Maximum	1.000	100.0	8975	13.30	88.89	168.0	12.0	600,000	857.3
Minimum	0.000	0.000	555	8.52	0.29	30.0	8.0	5,000	12.0
Std. Dev.	0.456	43.3	2110	0.98	9.86	20.4	1.08	87,673	88.2

Engineered Model Modifications – Student Density

CBECS acquires data noted as the EDSEAT variable on the number of students that can be seated in all classrooms in the building (or facility) at one time. Effectively, this represents the maximum seating capacity of the school which does not necessarily represent the average number of students in attendance over the previous 12 months. Based on the response of beta testers or an earlier version of the model, it was determined that the average number of students in attendance over the previous 12 months would be a significantly easier value to obtain than would be the maximum seating capacity of the building. Thus, an engineered modification to the model that mapped actual student density to EDSEAT density was developed.

Table-3 lists the EDSEAT density from CBECS as well as student density for approximately 1,000 K-12 schools located across the country obtained during the beta test period. Over the range of buildings exceeding 75,000 ft^2, the two values tracked very well with each other with EDSEAT density being typically 20 to 35 percent higher. However, for building less than 75,000 ft^2 a significant difference occurred.

A simple solution was developed where the equation describing the EDSEAT density was divided by the equation describing the student density resulting in an “adjustment factor” relating the two values to one another.

Table-3, EDSEAT Density and Student Density by Building Size

	Floorspace Bins									
	1,000 to 4,999	5,000 to 9,999	10,000 to 19,999	20,000 to 29,999	30,000 to 49,999	50,000 to 74,999	75,000 to 99,999	100,000 to 149,999	150,000 to 249,999	250,000 +
CBECS EDSEAT Density Fitted	25.13	19.75	15.52	13.48	11.28	9.80	8.87	7.70	6.45	
Actual	29.89	27.49	15.96	12.32	14.42	9.96	8.49	8.56	6.69	6.29
Student Density Fitted	8.05	8.00	7.89	7.78	7.56	7.28	7.01	6.46	5.36	
Actual	8.07	8.11	8.11	8.36	8.26	7.79	6.17	5.69	5.25	5.16

EDSEAT Density = $485.6(SQFT)^{-0.3477}$

Student Density = -0.000011(SQFT) + 8.107

Solving these two equations simultaneously resulted in an adjustment factor which is described by the equation:

$AF_{Students} = (485.6(SQFT)^{-0.3477}) / (-0.000011(SQFT) + 8.107)$

For the purposes of benchmarking, the tool asks for number of students which is then mapped to EDSEAT density via this adjustment factor.

Look-Up Table

Table-4 is used to compute the Energy Performance Rating (EPR) on a 1 to 100 scale seen by the user. The column of Actual Source EUI is the simple adjusted source energy intensity, in kBtu/ft^2-yr, obtained in applying the regression model to the CBECS records. Thus, these values represent a normalized Source EUI based on the CBECS dataset. The column of Fitted Source EUI takes the normalized Source EUI values and fits them to a gamma distribution. In fitting the Actual Source EUI, the value corresponding to an EPR of 75 – the minimum threshold for ENERGY STAR – is held constant. Once done, the values in the Fitted Source EUI column corresponding to the EPRs of 1 to 100 now represent the nominal look-up table used to assess an individual building's performance. The purpose of fitting the Source EUI values to a gamma distribution is to reduce the likelihood of "clustering" of Source EUI values about various EPRs. Early beta tests with the public indicated that this phenomena – where relatively large (2 or 3 points) movements in EPR would occur for small changes (< 1 kBtu/ft^2-year) in Source EUI – was confusing to the users.

Table-4 Energy Performance Rating, Adjusted Source EUI, and Fitted Source EUI

EPR	Actual Source EUI (kBtu/ft^2-yr)	Fitted Source EUI (kBtu/ft^2-yr)		EPR	Actual Source EUI (kBtu/ft^2-yr)	Fitted Source EUI (kBtu/ft^2-yr)
100	17.0	29.9		50	124.0	121.1
99	23.7	36.3		49	125.8	122.6
98	37.5	40.8		48	127.0	124.1
97	41.7	44.5		47	127.6	125.6
96	46.2	47.7		46	129.0	127.1
95	49.4	50.5		45	129.9	128.7
94	55.6	53.1		44	131.1	130.2
93	58.2	55.4		43	132.7	131.8
92	62.5	57.7		42	134.2	133.4
91	62.9	59.8		41	135.8	135.0
90	64.5	61.8		40	137.8	136.7
89	66.2	63.7		39	138.4	138.3
88	66.6	65.5		38	140.3	140.0
87	69.0	67.3		37	141.2	141.8
86	72.2	69.1		36	143.0	143.5
85	73.3	70.8		35	145.0	145.3
84	74.9	72.4		34	145.7	147.1
83	77.2	74.0		33	147.5	149.0
82	78.0	75.6		32	150.3	150.9
81	80.0	77.2		31	152.1	152.9
80	80.9	78.7		30	152.7	154.9
79	81.9	80.2		29	153.4	156.9
78	84.5	81.7		28	155.9	159.0
77	84.7	83.1		27	158.7	161.2
76	84.9	84.6		26	161.7	163.4
75	**86.0**	**86.0**		25	164.8	165.7
74	87.7	87.5		24	165.9	168.0
73	88.6	88.9		23	171.6	170.5
72	90.0	90.3		22	173.4	173.0
71	92.3	91.7		21	178.1	175.6
70	96.3	93.1		20	180.6	178.3
69	96.9	94.5		19	184.7	181.2
68	98.9	95.9		18	186.2	184.2
67	100.0	97.2		17	188.6	187.3
66	100.2	98.6		16	190.9	190.6
65	102.6	100.0		15	195.2	194.1
64	103.6	101.4		14	199.9	197.8
63	105.3	102.8		13	203.7	201.8
62	106.0	104.1		12	208.6	206.0
61	108.5	105.5		11	213.1	210.6
60	109.6	106.9		10	221.2	215.7
59	110.3	108.3		9	223.7	221.2
58	112.0	109.7		8	228.5	227.4
57	113.8	111.1		7	247.5	234.5
56	114.7	112.5		6	257.9	242.7
55	116.2	113.9		5	267.2	252.6
54	117.7	115.3		4	280.0	265.1
53	121.2	116.8		3	313.3	282.3
52	121.5	118.2		2	343.9	310.8
51	123.6	119.7		1	600.1	339.4

Assessing Performance

To assess the performance of a building via the Energy Performance Rating on the 1 to 100 scale, two calculations are made upon the user entering in the requisite data. First, as explained in the Weather Normalization file (downloadable at www.energystar.gov), the user's actual annual source energy intensity, in kBtu/ft^2-yr, is weather normalized to reflect the annual source energy intensity the building would have seen in a normal (i.e. 30-year average) weather year. In the second calculation, the regression model equation is used to calculate a predicted Source EUI value based on the operating characteristics entered by the user. This predicted Source EUI is then divided by the mean Source EUI of the regression model; yielding an adjustment factor. The adjustment factor is then applied to each of the Fitted Source EUI values corresponding to EPRs from 1 to 100 to provide a range of Customized Source EUI values. To calculate the EPR of the building, the building's weather normalized Source EUI is compared to Customized Source EUI values.

Table-5 is intended for use with the following example to illustrate how a EPR is determined for a given building. In this example, the actual Source EUI was weather normalized down approximately 3%; in essence meaning that over the course of the year in which the building's energy consumption was reported the building "experienced" a net 3% more severe weather year than normal.

Example Building

Area	=	50,000 ft^2	Students	=	650
Cook	=	yes ("yes" = 1; "no" = 0)	Weekly Hours	=	60
Cooling%	=	80	Months in Use	=	10
HDD	=	3200			

Actual Source EUI = 56.4 kBtu/ft^2-yr

Weather Norm. Source EUI = 54.7 kBtu/ft^2-yr

Regression Equation

Source EUI = $C_0 + C_1$ (Ln(SQFT)) + C_2 (COOK) + C_3(COOLP) + C_4(HDD) + C_5((485.63 x ($SQFT^{-0.3477}$))/(8.107 – 0.000011 x SQFT) x (STUDENTS/(SQFT/1000))) + C_6(WKHRS) + C_7(MONUSE)

Predicted Source EUI = 100.8 kBtu/ft^2-yr

Mean Source EUI = 132.3 kBtu/ft^2-yr

Adjustment Factor = (100.8 kBtu/ft^2-yr / 132.3 kBtu/ft^2-yr)
= 0.76

Table-6 Determining Energy Performance Rating

EPR	Fitted Source EUI (kBtu/ft^2-yr)	Adjustment Factor	Customized Source EUI (kBtu/ft^2-yr)
100	29.9	0.76	22.7
99	36.3	0.76	27.6
98	40.8	0.76	31.0
…	…	…	…
…	…	…	…
…	…	…	…
85	70.8	0.76	53.8
84	72.4	0.76	55.0
83	74.0	0.76	56.2
…	…	…	…
…	…	…	…
…	…	…	…
1	339.4	0.76	257.9

Note that when this model is placed onto the production site with the Energy Performance Rating software tool, users can include other space types to further characterize their building. These space types include office, computer rooms, garage space, and parking lots. With the exception of parking lots, these other space types, if used to characterize the building having K-12 space, are incorporated into the Energy Performance Rating by using weighted averages. If defined by the user, the energy impact associated with parking lots is simply added to the customized look up table.

Appendix A
Dataset Statistics after Application of Basic Filters and Screens

Distribution Amongst Census Divisions, K-12 (CBECS 1995)

	All Buildings	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
#	325	23	38	57	31	48	12	50	29	37
%	--	7%	12%	18%	10%	15%	4%	15%	9%	11%
Weighted #	121,977	4,039	8,672	9,207	9,747	17,777	2,293	28,795	10,739	30,708
%		3%	7%	8%	8%	15%	2%	24%	9%	25%
SqFt (000s)	24,649	2,433	3,479	5,799	2,503	3,198	884	3,104	1,878	1,373
%		10%	14%	24%	10%	13%	4%	13%	8%	6%
Weighted SqFt (000s)	4,175,347	353,392	594,537	672,372	364,397	585,029	119,508	707,404	348,803	429,905
%		8%	14%	16%	9%	14%	3%	17%	8%	10%
All-Elec	44	1	4	4	7	13	4	0	5	6
%	14%	4%	11%	7%	23%	27%	33%	0%	17%	16%
Gas	244	16	28	52	20	23	8	47	23	27
%	75%	70%	74%	91%	65%	48%	67%	94%	79%	73%
Oil	67	18	17	3	4	17	1	0	1	6
%	21%	78%	45%	5%	13%	35%	8%	0%	3%	16%
Steam	8	0	3	0	2	0	0	3	0	0
%	2%	0%	8%	0%	6%	0%	0%	6%	0%	0%